Year: 2018

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DOI: https://doi.org/10.1159/000494247

Originally published at:
Buhl, Christof; Artemiev, Dmitri; Pfiffner, Flurin; Swanenburg, Jaap; Veraguth, Dorothe; Roosli, Christof; Huber, Alexander; Dalbert, Adrian (2018). Dynamic Postural Stability and Hearing Preservation after Cochlear Implantation. Audiology and Neurotology, 23(4):222-228.
DOI: https://doi.org/10.1159/000494247

Original Paper

Audiology & Neurotology

Audiol Neurotol 2018;23:222–228
DOI: 10.1159/000494247

Received: July 10, 2018
Accepted after revision: October 2, 2018
Published online: November 14, 2018

Dynamic Postural Stability and Hearing Preservation after Cochlear Implantation

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Keywords

Cochlear implant · Cochlear implantation · Functional gait assessment · Postural stability · Dynamic postural stability · Balance · Hearing preservation

Abstract

Objectives: (1) To assess dynamic postural stability before and after cochlear implantation using a functional gait assessment (FGA). (2) To evaluate the correlation between loss of residual hearing and changes in dynamic postural stability after cochlear implantation. ***Methods:*** Candidates for first-sided cochlear implantation were prospectively included. The FGAs and pure-tone audiograms were performed before and 4–6 weeks after cochlear implantation. ***Results:*** Twenty-three subjects were included. Forty-eight percent ($n = 11$) showed FGA performance below the age-referenced norm before surgery. One subject had a clinically relevant decrease of the FGA score after cochlear implantation. No significant difference between the mean pre- and postoperative FGA scores was detectable ($p = 0.4$). Postoperative hearing loss showed no correlation with a change in FGA score after surgery ($r = 0.3$, $p = 0.3$, $n = 16$). ***Conclusion:*** Single-sided cochlear implantation does not adversely affect dynamic postural stability 5 weeks after surgery. Loss of functional residual hearing is not correlated with a decrease in dynamic postural stability.

Introduction

Cochlear implantation is a routine procedure for auditory rehabilitation in patients with profound hearing loss or deafness. After surgery, vestibular dysfunction or balance disorders can occur. The frequency of such incidents is controversial and the numbers reported in the literature vary greatly [Buchman et al., 2004; Stevens et al., 2014; Ibrahim et al., 2017]. Possible underlying mechanisms may include direct trauma caused by electrode insertion, acute serous labyrinthitis, reaction to a foreign body, endolymphatic hydrops, and electrical stimulation [Katsiari et al., 2013; Ibrahim et al., 2017]. Multiple studies have demonstrated damage to the semicircular canals [Buchman et al., 2004; Migliaccio et al., 2005; Enticott et al., 2006; Filipo et al., 2006; Kluenter et al., 2009, 2010; Krause et al., 2009, 2010] and otolith organs [Basta et al., 2008; Melvin et al., 2009; Krause et al., 2010]. A recent

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review showed a significant negative effect on the results of caloric as well as vestibular-evoked myogenic potential tests [Ibrahim et al., 2017]. However, such findings insufficiently reflect subjective complaints [Jacobson et al., 1991; Perez et al., 2003; McCaslin et al., 2011] and there is controversy about their clinical significance.

Comparatively few studies have investigated the influence of cochlear implantation on postural stability. Kluenter et al. [2009, 2010] and Buchman et al. [2004] found no negative effect on postural stability approximately 1 month after surgery. Stevens et al. [2014] found a decrease in static postural stability 2 weeks after surgery.

The functional gait assessment (FGA) is a well-evaluated test to assess dynamic postural stability during various walking tasks [Wrisley et al., 2004]. Age-referenced norms for performance are available [Walker et al., 2007], and a correlation with fall risk has been shown [Wrisley et al., 2004]. To our knowledge, results of the FGA in cochlear implant (CI) recipients have not been reported. Furthermore, it remains unclear whether there is a correlation between loss of residual hearing and a decrease in postural stability. Such a correlation could be explained by similar pathomechanisms of hearing loss and vestibular dysfunction after cochlear implantation [Carlson et al., 2012; Katsiari et al., 2013; Ibrahim et al., 2017].

This study aimed to: (1) assess whether dynamic postural stability in CI recipients assessed by the FGA was below age-referenced norms before surgery and whether it decreased 4 weeks after surgery, and (2) evaluate whether there was a correlation between loss of residual hearing and a decrease in dynamic postural stability after cochlear implantation.

Methods

The study protocol was approved by the Ethics Committee of Zurich (KEK-ZH No. 2015-0454). All subjects were adult candidates (aged ≥18 years) for first-sided cochlear implantation at the CI center of the University Hospital of Zurich, Zurich, Switzerland. Each subject provided written informed consent prior to the surgery. Exclusion criteria were second-sided or bilateral cochlear implantation, an inability to follow the instructions required for the FGA, orthopedic problems preventing normal gait, a preexisting diagnosis associated with vertigo or a balance disturbance, a high-grade vision impairment, or alcohol abuse. The preoperative vestibular function of all 3 semicircular canals was assessed within 1 month prior to surgery in all subjects using the video head impulse test (Otometrics, Natus Medical Denmark, Taarstrup, Denmark). The assessed parameters were the vestibular-ocular reflex gain (normal >0.8 for the horizontal semicircular canals and >0.7 for the anterior and posterior semicircular canals) and the appearance of saccades.

Functional Gait Assessment

The FGA was performed before surgery and 4–6 weeks after surgery during routine visits to the clinic for CI fitting. it was conducted according to Wrisley et al. [2004] and included 10 tasks. (1) Gait level surface (instruction: Walk at your normal speed from here to the next mark [6 m]). (2) Change in gait speed (instruction: Begin walking at your normal pace [for 1.5 m]. When I tell you "Go," walk as fast as you can [for 1.5 m]. When I tell you "Slow," walk as slowly as you can [for 1.5 m]). (3) Gait with horizontal head turns (instruction: Walk from here to the next mark [6 m away]. Begin walking at your normal pace. Keep walking straight and then after 3 steps, turn your head to the right and keep walking straight while looking to the right. After 3 more steps, turn your head to the left and keep walking straight while looking left. Continue looking alternately right and left every 3 steps until you have completed 2 repetitions in each direction). (4) Gait with vertical head turns (instruction: Walk from here to the next mark [6 m]. Begin walking at your normal pace. Keep walking straight while looking up. After 3 more steps, tip your head down and then keep walking straight while looking down. Continue looking alternately up and down every 3 steps until you have completed 2 repetitions in each direction). (5) Gait and pivot turn (instruction: Begin with walking at your normal pace. When I tell you, "Turn and stop," turn as quickly as you can to face the opposite direction and stop). (6) Step over obstacle (instruction: Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and then keep walking). (7) Gait with a narrow base of support (instruction: Walk on the floor with arms folded across the chest, feet aligned heel-to-toe in tandem for 3.6 m). The number of steps taken in a straight line are counted for a maximum of 10 steps. (8) Gait with eyes closed (instruction: Walk at your normal speed from here to the next mark [6 m] with your eyes closed). (9) Ambulating backwards (instruction: Walk backwards until I tell you to stop). (10) Steps (instruction: Walk up these stairs as you would at home [i.e., using the rail if necessary]. At the top, turn around and walk down).

Each task is rated on a scale of 0–3 points. A score of 3 points is defined as normal performance, 2 points as mild impairment, 1 point as moderate impairment, and 0 points as severe impairment. The minimal clinically important difference between 2 FGA scores is defined as 4 points [Beninato et al., 2014]. Age-referenced norms for FGA performance were taken from Walker et al. [2007]. The FGA was conducted by physical therapists at the Department of Physiotherapy, University Hospital of Zurich, Switzerland. The assessors of the FGA were blinded towards the results of the pure-tone audiograms.

Pure-Tone Audiogram

Pure-tone audiograms were conducted in accordance with ISO 8253–1 and were performed prior to surgery and 4–6 weeks after surgery. Behavioral air-conduction hearing thresholds were measured. According to Van Abel et al. [2015], functional residual hearing was defined as a low-frequency pure-tone average at 250 and 500 Hz no poorer than 85 dB HL. In subjects with functional residual hearing before surgery, the threshold shift 4–6 weeks after surgery was assessed. The maximum audiometer output was 100 dB HL at 250 Hz and 120 dB HL at 500 Hz. If a response was considered vibrotactile, or questionable vibrotactile, it was considered as no response. The assessors of the pure-tone audiogram were blinded towards the results of the FGA.

Table 1. Subject demographics, FGA scores, and audiometric findings

Subject No.	Age, years	Side, L/R	Type of CI	Etiology of hearing loss	Pre-OP vestibular function[d]	Pre-OP FGA	Post-OP FGA	Pre-OP PTA, dB HL	Ipsilateral hearing loss	Contralateral hearing loss
1	46	L	Nucleus CI-512	idiopathic	normal	26[a]	27	no residual functional hearing	n.a.	n.a.
2	79	R	Nucleus CI-512	idiopathic	normal	22[a]	15[b]	85	30	2.5
3	74	R	HiRes90K HiFocus V	idiopathic	normal	30	30	55	17.5	0
4	41	R	Nucleus CI-512	idiopathic	normal	26[a]	23	82.5	32.5	0
5	41	L	Nucleus CI-522	idiopathic	normal	28[a]	29	85	0	–5
6	56	L	Nucleus CI-522	idiopathic	normal	30	30	no residual functional hearing	n.a.	n.a.
7	45	R	Nucleus CI-512	idiopathic	normal	28[a]	28	67.5	17.5	2.5
8	42	L	Nucleus CI-512	idiopathic	normal	29	29	75	40	–2.5
9	54	L	HiRes90K HiFocus V	otosclerosis	normal	28	28	82.5	32.5	0
10	61	L	Nucleus CI-512	idiopathic	normal	16[a]	16	62.5	27.5	0
11	40	L	Nucleus CI-522	large vestibular aqueduct syndrome	normal	30	30	65	20	2.5
12	83	R	Nucleus CI-512	idiopathic	bilateral posterior semicircular canal LoF	28	29	70	45	–5
13	74	R	HiRes90K HiFocus V	idiopathic	normal	26	26	72.5	42.5	–5
14	54	L	Nucleus CI-522	idiopathic	normal	29	30	80	10	0
15	83	R	HiRes90K HiFocus V	idiopathic	normal	20	22	37.5	22.5	2.5
16	60	L	HiRes90K HiFocus V	idiopathic	LoF (R) horizontal, anterior, and posterior semicircular canals	30	28	no residual functional hearing	n.a.	n.a.
17	57	R	HiRes90K HiFocus V	idiopathic	normal	25[a]	29[c]	no residual functional hearing	n.a.	n.a.
18	31	R	Nucleus CI-522	idiopathic	normal	26[a]	27	37.5	5	2.5
19	62	L	Nucleus CI-522	idiopathic	normal	26[a]	25	32.5	57.5	2.5
20	63	L	Nucleus CI-422	idiopathic	normal	30	30	37.5	45	2.5
21	66	R	Nucleus CI-512	idiopathic	normal	16[a]	22[c]	no residual functional hearing	n.a.	n.a.
22	81	R	Nucleus CI-512	idiopathic	normal	22	23	no residual functional hearing	n.a.	n.a.
23	63	R	Nucleus CI-512	idiopathic	normal	26[a]	27	no residual functional hearing	n.a.	n.a.

FGA, functional gait assessment; L, left; R, right; CI, cochlear implant; OP, operative; PTA, pure-tone average at 250 and 500 Hz; LoF, loss of function; n.a., not applicable.
[a] Preoperative FGA score below age-referenced norms (according to Walker et al. [2007]).
[b] Postoperative FGA score ≥4 points below the preoperative FGA score.
[c] Postoperative FGA score ≥4 points above the preoperative FGA score.
[d] Assessed by video head impulse test.

Statistical Analysis

Statistical analyses were conducted with SPSS v25 (IBM, Armonk, NY, USA). As the distribution of the FGA scores and hearing thresholds did not follow a Gaussian distribution, the pre- and postoperative means were analyzed using the Wilcoxon matched-pairs signed-rank test. The Kruskal-Wallis test with Dunn-Bonferroni correction for multiple comparisons was used to detect significant differences between average performances in different FGA tasks. To compare the mean change of the FGA scores between subgroups (i.e., subjects ≥60 years and <60 years, subjects with and without preoperative FGA scores below age-referenced norms), the Mann-Whitney U test was used. To evaluate a correlation between changes in the FGA score and time between surgery and postoperative FGA as well as between changes in the FGA score and postoperative hearing loss, the Spearman correlation was performed. Significance was set at $p \leq 0.05$.

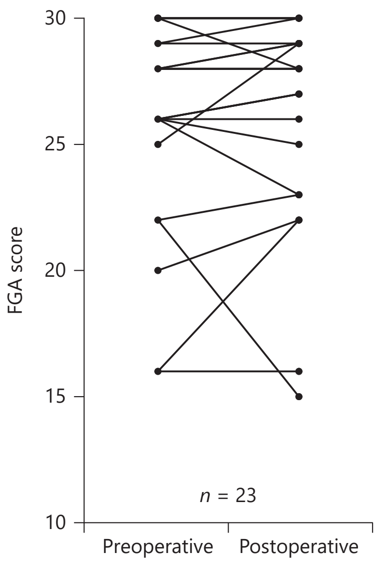

Fig. 1. Pre- and postoperative functional gait assessment (FGA) score for each subject.

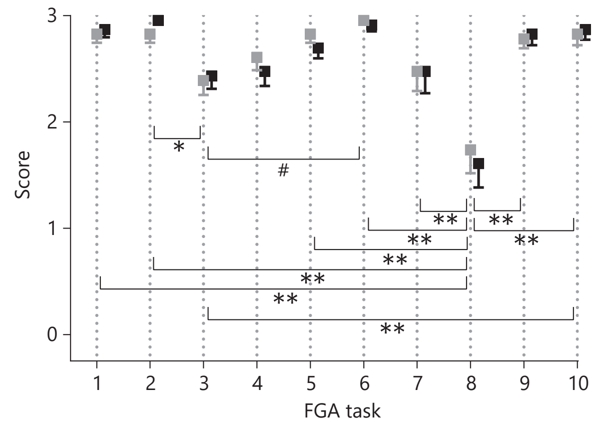

Fig. 2. Mean functional gait assessment (FGA) score for each task before (black squares) and after (grey squares) cochlear implantation. On average, CI recipients performed the poorest for Task 8 (gait with eyes closed). The standard error of the mean is shown. Statistically significant differences: * preoperatively, ** pre- and postoperatively, and # postoperatively (Kruskal-Wallis test with Dunn-Bonferroni correction).

Results

Twenty-three subjects (9 females and 14 males) were included. Mean age was 70 (median 66, standard deviation [SD] = 15, range 31–83) years. All subjects except S12 and S16 had normal vestibular function of all 3 semicircular canals before surgery. Subject S12 had a loss of function of both posterior semicircular canals and S16 had a loss of function of all 3 semicircular canals on the right side but was implanted on the left side. Therefore, no subject had minimal or no remaining vestibular function prior to surgery on the operated side. Etiology of hearing loss was unknown apart from 1 subject with otosclerosis and another with large vestibular aqueduct syndrome. Subject demographics, preoperative vestibular function, FGA scores, and audiometric findings are summarized in Table 1.

Dynamic Postural Stability

Mean duration between preoperative FGA and surgery was 2 (SD = 1.3) days. Mean FGA score before surgery was 26 (SD = 4.1, n = 23). Mean duration between surgery and the postoperative FGA was 37 (SD = 21) days. There was no correlation between the time between surgery and the postoperative FGA ($r_s = 0.09$, $p = 0.7$, $n = 23$, Spearman's correlation). The mean postoperative FGA score was 26.2 (SD = 4.2, 2 n = 23). The difference was not statistically significant ($Z = 0.9$, $p = 0.4$, Wilcoxon matched-pairs signed-rank test) (Fig. 1).

On average, Task 8 (gait with eyes closed) showed the poorest performance before and after surgery (mean score before = 1.6, SD = 1.1, $H = 63.7$, $p < 0.0001$; after = 1.7, SD = 1, $H = 50.6$, $p < 0.0001$; Kruskal-Wallis test with Dunn-Bonferroni correction) (Fig. 2). Eleven subjects (48%) had an FGA performance below the age-referenced norm before surgery. One subject (S2) showed a relevant decrease in FGA score (from 22 to 15) after surgery and 2 (S17 and S21) showed a relevant increase (from 25 to 29 and 16 to 22, respectively) (Table 1).

Eleven subjects were ≥60 years old (mean change of FGA score 0.1, SD = 3.1) and 12 were <60 years old (mean change of FGA score 0.4, SD = 1.5) (U = 64, $p = 0.9$, Mann-Whitney U test). Mean change in FGA score was 0.3 (SD = 3.4, n = 11) in subjects with an FGA score below the age-referenced norms before surgery, and 0.3 (SD = 1, n = 12) (U = 60, $p = 0.7$, Mann-Whitney U test) in subjects with normal FGA scores before surgery.

Hearing Preservation

Sixteen subjects had functional residual hearing before surgery (mean pure-tone average [at 250 and 500 Hz] 64 dB HL (SD = 18 dB). Mean duration between surgery and the postoperative pure-tone audiogram was 42 (SD = 13)

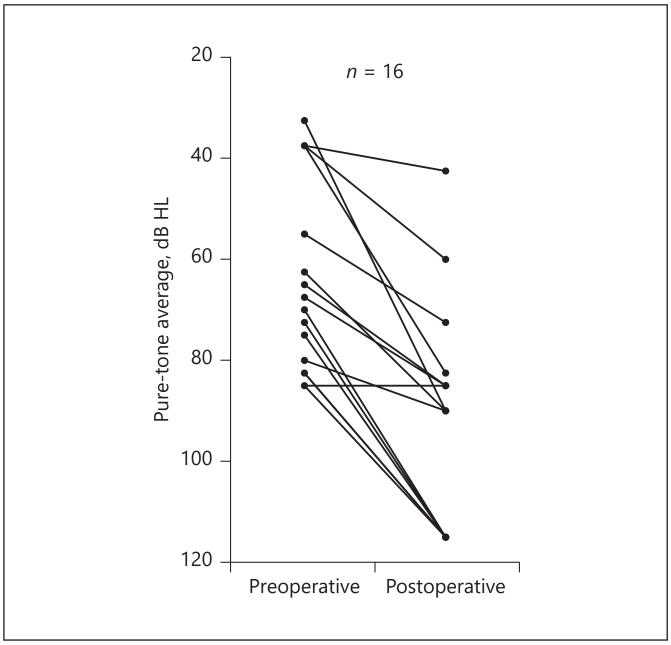

Fig. 3. Pre- and postoperative pure-tone average (PTA) at 250 and 500 Hz in all subjects with a PTA no poorer than 85 dB HL before surgery.

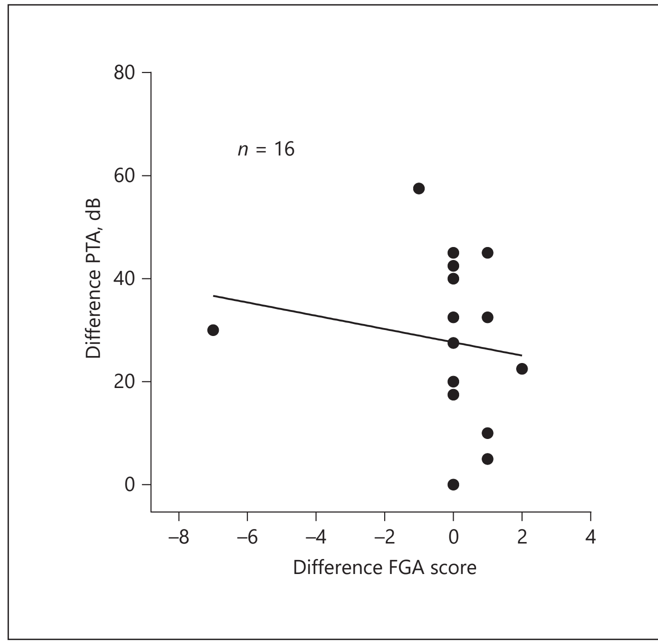

Fig. 4. Correlation between change in the functional gait assessment (FGA) score after surgery and postoperative hearing loss.

days. After surgery, the mean pure-tone average was 92 dB HL (SD = 21 dB) ($Z = 3.4$, $p = 0.001$, Wilcoxon matched-pairs signed rank test) (Fig. 3). In 44 % (7/16) of all subjects, functional residual hearing could be preserved after cochlear implantation. Mean hearing loss after cochlear implantation was 28 dB (SD = 15 dB).

Correlation between Dynamic Postural Stability and Hearing Preservation

In all 16 subjects with functional residual hearing before surgery, the correlation between change in FGA score after surgery and postoperative hearing loss was assessed. The analysis showed no correlation ($r_s = 0.3$, $p = 0.3$, $n = 16$, Spearman's correlation) (Fig. 4).

Discussion

The incidence and clinical significance of balance disorders after cochlear implantation is controversial. In this study, we evaluated changes in balance performance after cochlear implantation using the FGA. The FGA has been designed to detect changes in gait performance in patients with vestibular disorders [Whitney et al., 2004; Walker et al., 2007], and especially to assess fall risk. To our knowledge, it has not been used to assess dynamic postural stability after cochlear implantation. The results of caloric as well as vestibular-evoked myogenic potential tests are negatively influenced by cochlear implantation [Ibrahim et al., 2017], so our hypothesis was that changes in vestibular function might be reflected by a decrease in FGA score. Furthermore, we were interested in the correlation between hearing loss and a change in gait performance after surgery because of proposed similarities in the underlying mechanisms for postoperative hearing loss [Carlson et al., 2012] and a loss of vestibular function after cochlear implantation [Katsiari et al., 2013; Ibrahim et al., 2017]. We assumed that a correlation between hearing loss and a decrease in FGA score might exist.

On average, the FGA score remained unchanged approximately 37 days after surgery. Only 1 subject (S2) showed a relevant decrease in FGA score, and 2 (S17 and S21) even showed a relevant increase. This finding is in agreement with previous reports that detected no change in static postural stability (assessed by computerized dynamic platform posturography) [Buchman et al., 2004] or in dynamic postural stability (assessed by the Rhythmic Weight-Shift test, the Walk Across test, and the Tandem Walk test) [Kluenter et al., 2009, 2010] approximately 1 month after surgery. Similar to our findings, Kluenter et al. [2009] and Buchman et al. [2004] reported an improvement in postural stability in some CI recipients. By contrast, Stevens et al. [2014] found significantly poorer static postural stability (eyes-closed on foam task) within the first 2 weeks after surgery in 9 out of 16 subjects, and only 1 had an improved performance. The most obvious difference here is that Stevens et al. [2014], compared to our study, Kluenter et al. [2009, 2010], Buchman et al. [2004], had an earlier postoperative testing time. Overall, this suggests that postural stability may be impaired during the first 2–3 weeks but has recovered by 4–6 weeks after cochlear implantation, which is the approximate time that CI recipients return to the hospital for the CI fitting.

In the detailed analysis of the FGA, the poor performance for Task 8 among CI recipients stands out. In this task, subjects have to walk at their normal speed with their eyes closed. We hypothesize that this task challenges CI recipients more than average because orientation with closed eyes is more difficult for subjects with profound hearing loss or deafness than for people with normal hearing. An alternative explanation would be an underlying vestibulopathy, although all subjects (except for 2) with a partial loss of vestibular function had normal vestibular function preoperatively according to the video head impulse test. The below-average performance for Task 8 may also have contributed, at least in part, to the high percentage of below-age-referenced performance before surgery. Despite the fact that cochlear implantation does not adversely affect FGA performance in most cases, 48% of subjects showed dynamic postural stability below the age-referenced norms before surgery. This finding is in agreement with all previous studies assessing static [Buchman et al., 2004; Stevens et al., 2014] or dynamic [Kluenter et al., 2009, 2010] postural stability.

Stevens et al. [2014] found CI recipients ≥60 years old and CI recipients with preoperatively impaired balance performance were at a higher risk of suffering from a decrease in postural stability after cochlear implantation. In our study, although the only subject with a clinically relevant decrease in FGA score had a score below the age-referenced norms before surgery and was >60 years old, such a difference in outcome between subgroups could not be detected. Nevertheless, it must be highlighted that all 4 subjects with a preoperative FGA score <25 were >60 years old and the only subject with a relevant decrease in FGA score after surgery was among these subjects.

Preservation of functional acoustic hearing could be achieved in 44% of subjects with functional acoustic hearing. This corresponds well with previously published data [Van Abel et al., 2015]. No correlation was found between loss of residual hearing and changes in postural stability ($r = 0.38$, Spearman's correlation). Therefore, loss of residual hearing does not seem to be a risk factor for a decrease in postoperative balance performance.

Overall, an increase of fall risk ≥4 weeks after cochlear implantation seems to occur in only about 4% of unilateral CI recipients. Older age groups and subjects with preoperatively low FGA scores seem to be at a higher risk. Still, with this low rate, it seems plausible to assume that temporary declines in balance that seem to occur regularly in the first 2–3 weeks after cochlear implantation [Stevens et al., 2014] have a high rate of spontaneous recovery.

It should be stated that this study investigated balance performance before and after cochlear implantation in a very specific subgroup of unilateral CI recipients. Therefore, the conclusions drawn from these findings cannot be generalized. This holds true particularly for patients with second-sided or bilateral cochlear implantation or those with preexisting vestibular disorders (e.g., Meniere's disease) who receive a CI. Further research is needed to elucidate the effect of cochlear implantation on the postural stability in such patients.

Conclusion

In agreement with previous reports, the FGA before surgery showed a balance performance below the average in approximately 50% of CI recipients. Single-sided cochlear implantation did not adversely affect dynamic postural stability 5 weeks after surgery. Loss of functional residual hearing was not correlated with a decrease in dynamic postural stability.

Disclosure Statement

The authors have no conflicts of interest to disclose.

Funding Sources

The authors received no specific funding for this work.

Audiol Neurotol 2018;23:222–228
DOI: 10.1159/000494247

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